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Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Davoudinejad, A., & Tosello, G. (2017). *3D Finite Element Modelling of Drilling Process of Al2024-T3 Alloy with solid tooling and Experimental Validation*. Poster session presented at euspen's 17th International Conference & Exhibition, Hannover, Germany.

European Society for Precision Engineering and Nanotechnology (euspen), 17th International Conference, Hannover (Germany), 29th May – 2nd June 2017

3D Finite Element Modeling of Drilling Process of Al2024-T3 Alloy with solid tooling and Experimental Validation

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Abstract

Drilling is an indispensable process for many manufacturing industries due to the importance of the process for assembling components. This study presents a 3D finite element modeling (3D FEM) approach for drilling process of aluminum 2024-T3. The 3D model of tool for two facet HSSCo and four facet HSS were generated base on the details geometry. The simulations were carried out for both drills in different cutting conditions. The numerically obtained thrust forces were compared against experimental results. The tool stress distribution, chip formation and temperature distribution in the chip area were determined numerically. The results confirm the ability and advantage of 3D FE model of the drilling process.

3D Finite Element Modeling (3D FEM)

- Objective ⇒ Evaluate different drills geometry and material for drilling Aluminum 2024-T3.
- Reduction in cost and time, mainly with advance of powerful computers to predict parameters such as stress, cutting force, temperature, strain and strain rate, which are difficult or impossible to detect experimentally [1].
- Tool modeling and cutting configuration setup (Fig. 1).
  - Different cutting tool geometries (Table 1).
- Tool and workpiece were meshed with the 4 node tetrahedral elements, type.
- Adaptive-meshing technique was applied constantly in the simulations.
- The Power Law constitutive material model. where σ_0 is the initial yield stress, ε^p is the plastic strain, ε_0^p is the reference plastic strain, $\dot{\varepsilon}$ is the strain rate, $\dot{\varepsilon}_0$ is the reference plastic strain rate, c0 through c5 are the coefficients for the polynomial fit, T is temperature, n is the strain hardening exponent and m is the strain rate sensitivity coefficient [2].

$$\sigma(\varepsilon^p, \dot{\varepsilon}, \mathrm{T}) = \mathrm{g}(\varepsilon^p).\Gamma(\varepsilon).\Theta(\mathrm{T})$$

$$\mathrm{g}(\varepsilon^p) = \sigma_0 \, (1 + \frac{\varepsilon^p}{\varepsilon_0^p})^{1/n}$$

$$\Gamma(\varepsilon) = \sigma_0 \, (1 + \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0})^{1/m}$$

$$\Theta(\mathrm{T}) = c_0 + c_0 T^1 + \cdots + c_5 T^5$$

The friction phenomenon at the chip-tool interface was modeled using the Coulomb law. Based on the experimental research results and related studies [3] a constant friction factor of 0.7 is used in the finite element (FE) model.

$$\tau = \mu_{\sigma_n}$$

In order to validate model a comparison between numerical and experimental forces were carried out.

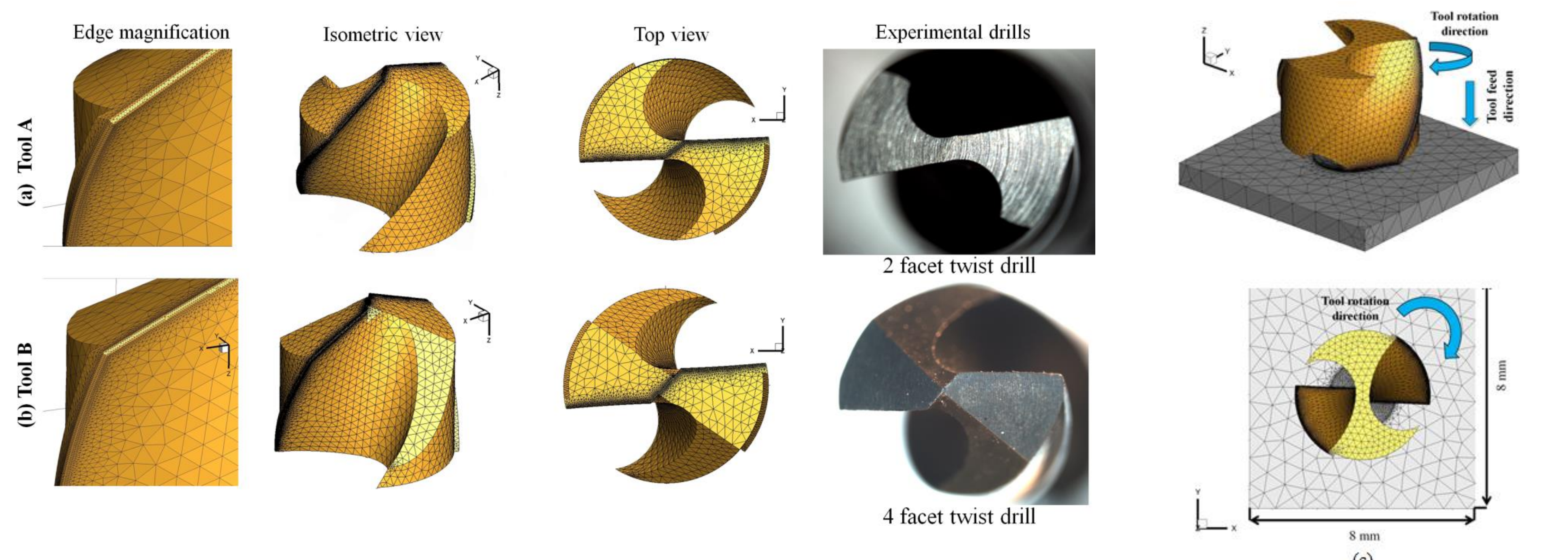

Fig. 1 Tool 3D model and experimental image (a) two facet HSSCo (b) four facet HSS (c) 3D FE model for drilling setup

Experimental procedure for FEM validation

Table 1 Cutting tool specifications

	Tool A	Tool B
Material	HSSCo	HSS
Code	A920	A120
Hardness (HV)	980	918
Geometry	2 Facet	4 Facet
Diameter (mm)	6	6
No of flutes	2	2
Helix angle	40°	30°
Chisel edge angle	130°	130°
Lip relief angle	10°	15°
Point angle	130°	130°
Web thickness (mm)	0.6	1

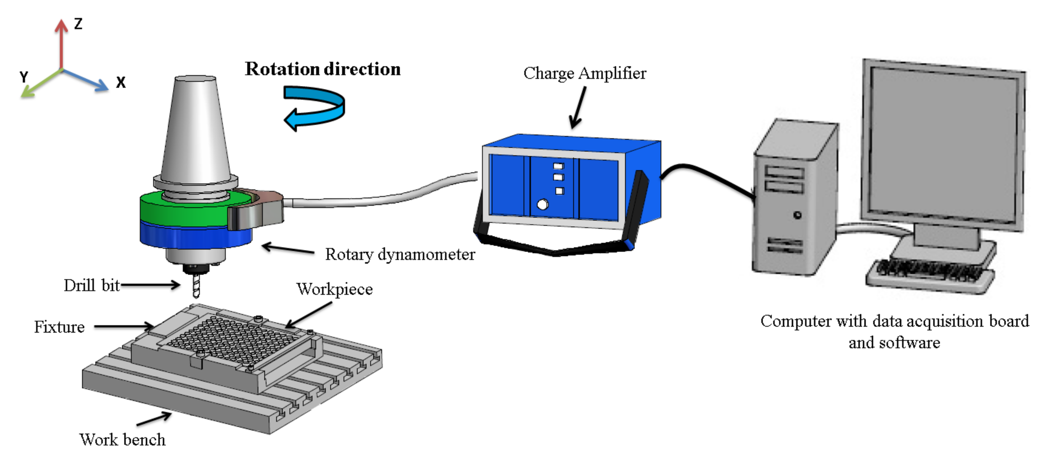

Fig. 2 The schematic representation of the experimental set-up.

- Dry drilling experiments of Al2024 were carried out using CNC Deckel Maho DMC 835 [4].
- Cutting speed (94.2 m/min)
- Feed rates (0.04, 0.4 mm/rev) [4].

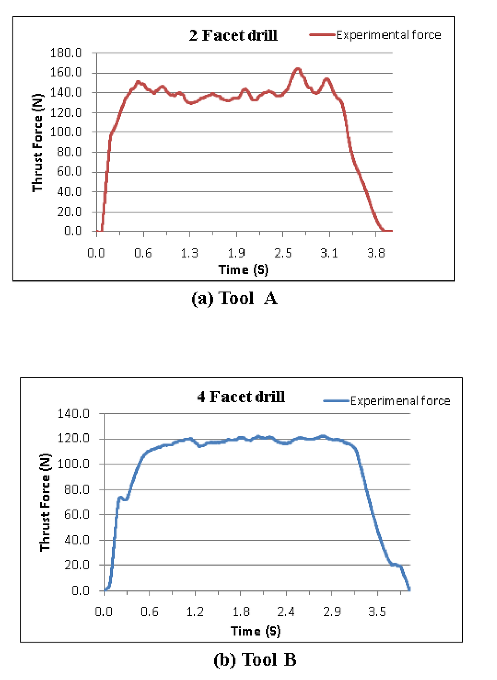

Fig. 3 Experimental thrust force (a) 2 facet drill and (b) 4 facet drill at fz = 0.04 mm/rev

FEM results

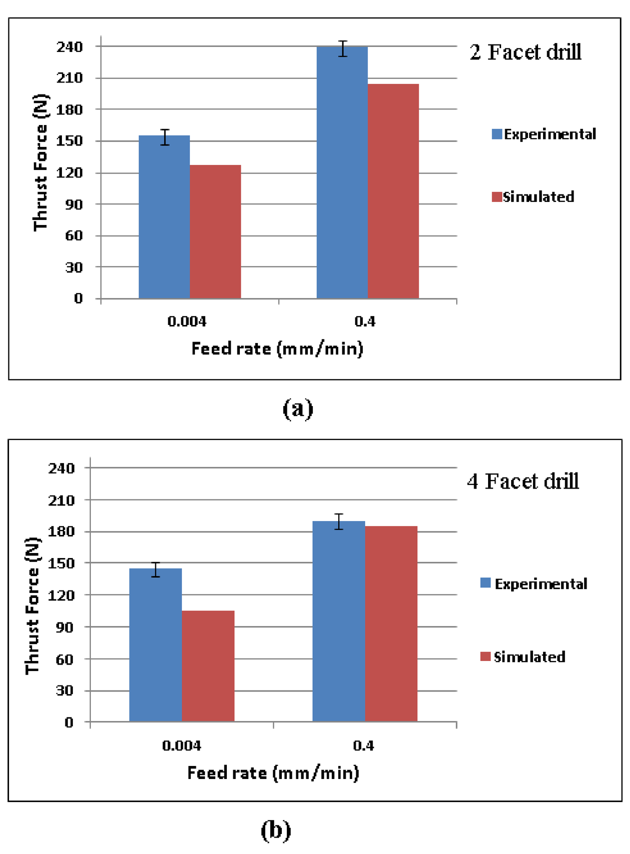

Fig. 4 Comparison of FE Model and experimental thrust force

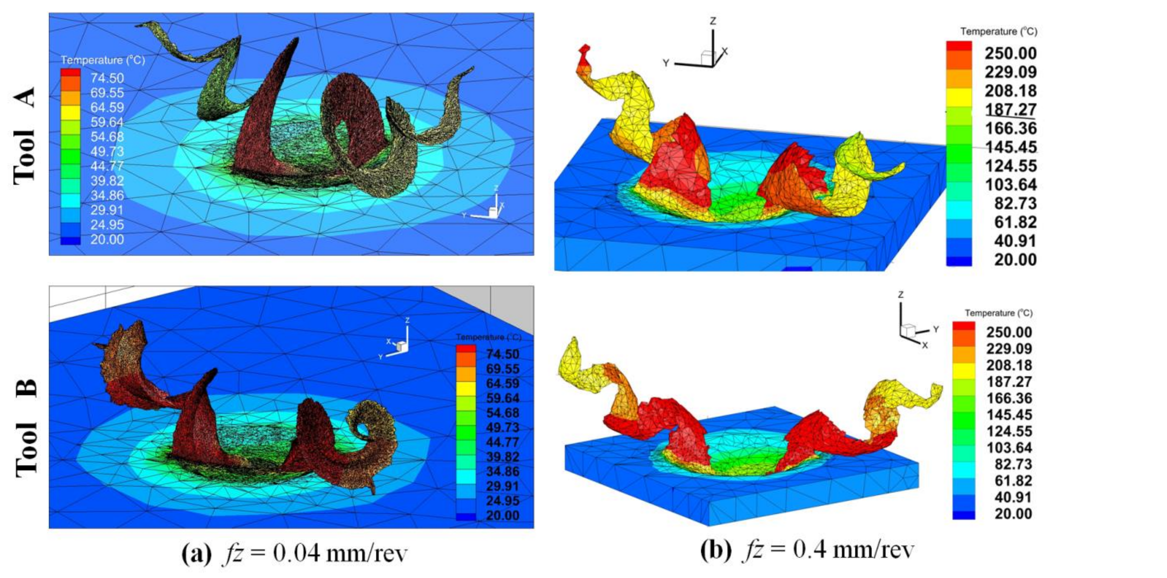

Fig. 5 Chip formation and temperature distribution obtained at the end of simulations

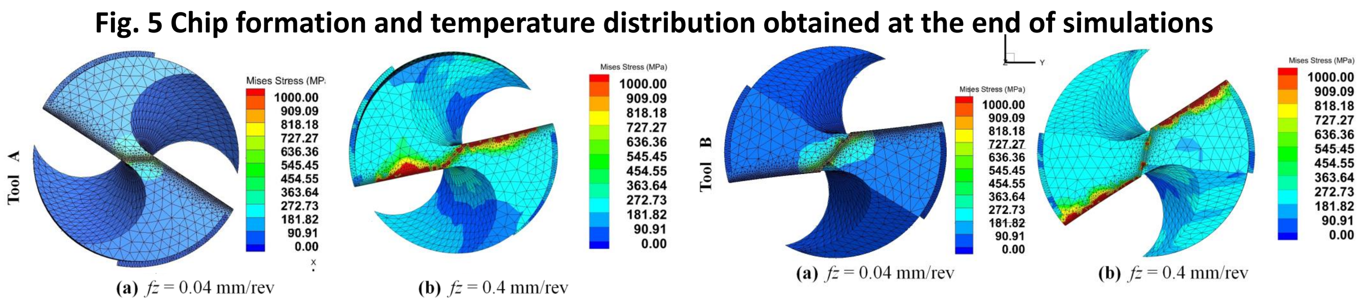

Fig. 6 Stress values at different cutting conditions (a) *fz* = 0.04 mm/rev (b) *fz* = 0.4 mm/rev

- The maximum deviation between the experimental and numerical results is obtained from the drilling processes under drilling conditions *Vc* = 94.2 m/min and *fz* = 0.4 mm/rev with the 2 facet drill.
- The thrust forces obtained with the 4 facet drill were about 15-20% less than 2 facet drill.

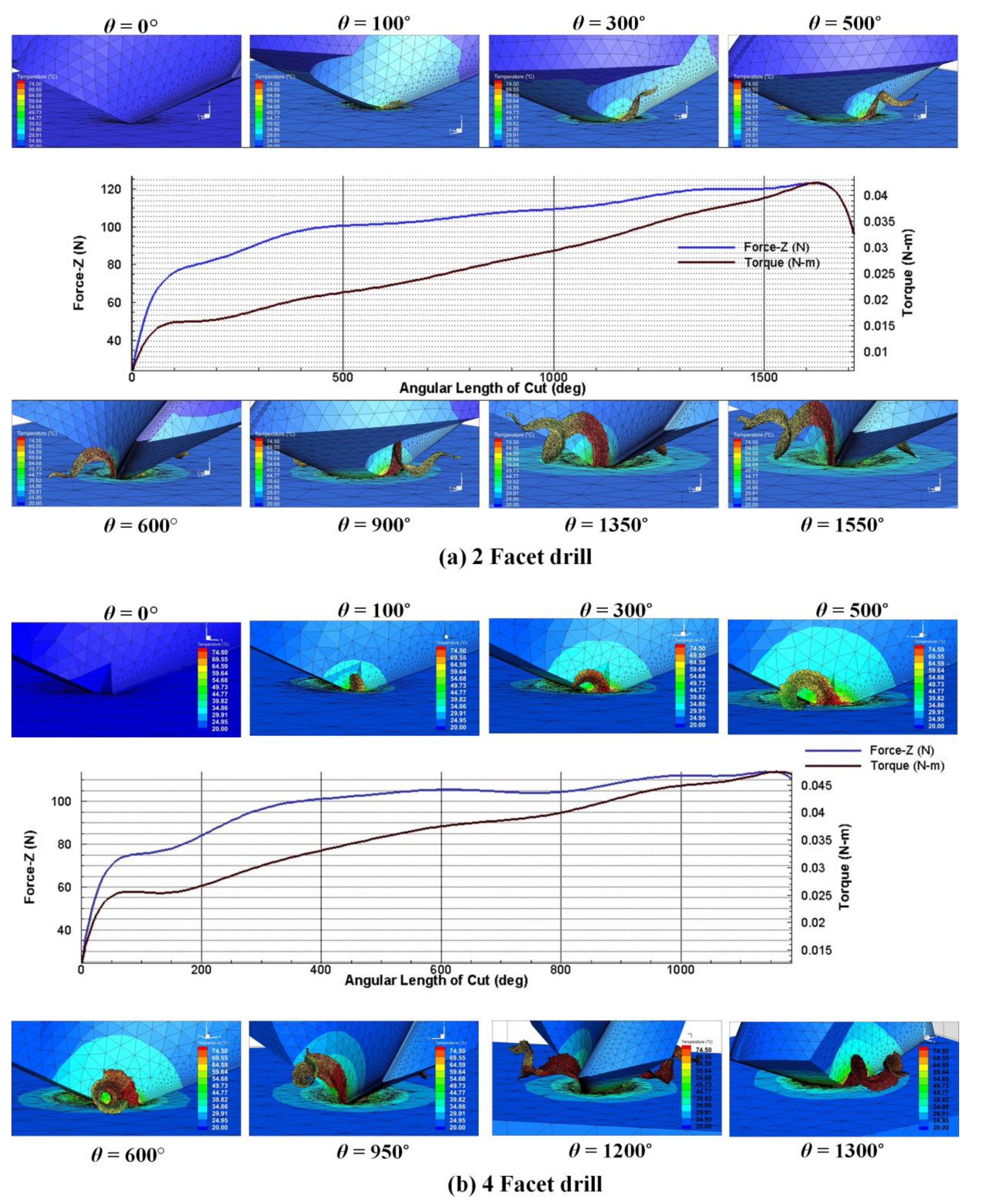

Fig. 7 Chip formation, thrust force and torque in different angular positions (a) 2 facet drill (b) 4 facet drill at *fz* = 0.04 mm/rev

Conclusion

3D finite element modeling of the drilling process of aluminum 2024-T3 alloy with two and four-facet drills geometry were carried out at different cutting conditions. Comparable results of FE model and experimental thrust force were observed. The performance comparison of the simulations result reveals the 4-facet drill geometry mainly in terms of thrust force and stress distribution along the cutting edges demonstrates a better performance. Higher force obtained at the same cutting condition with 2-facet drill and the maximum stress occurs on the chisel and cutting edges.

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